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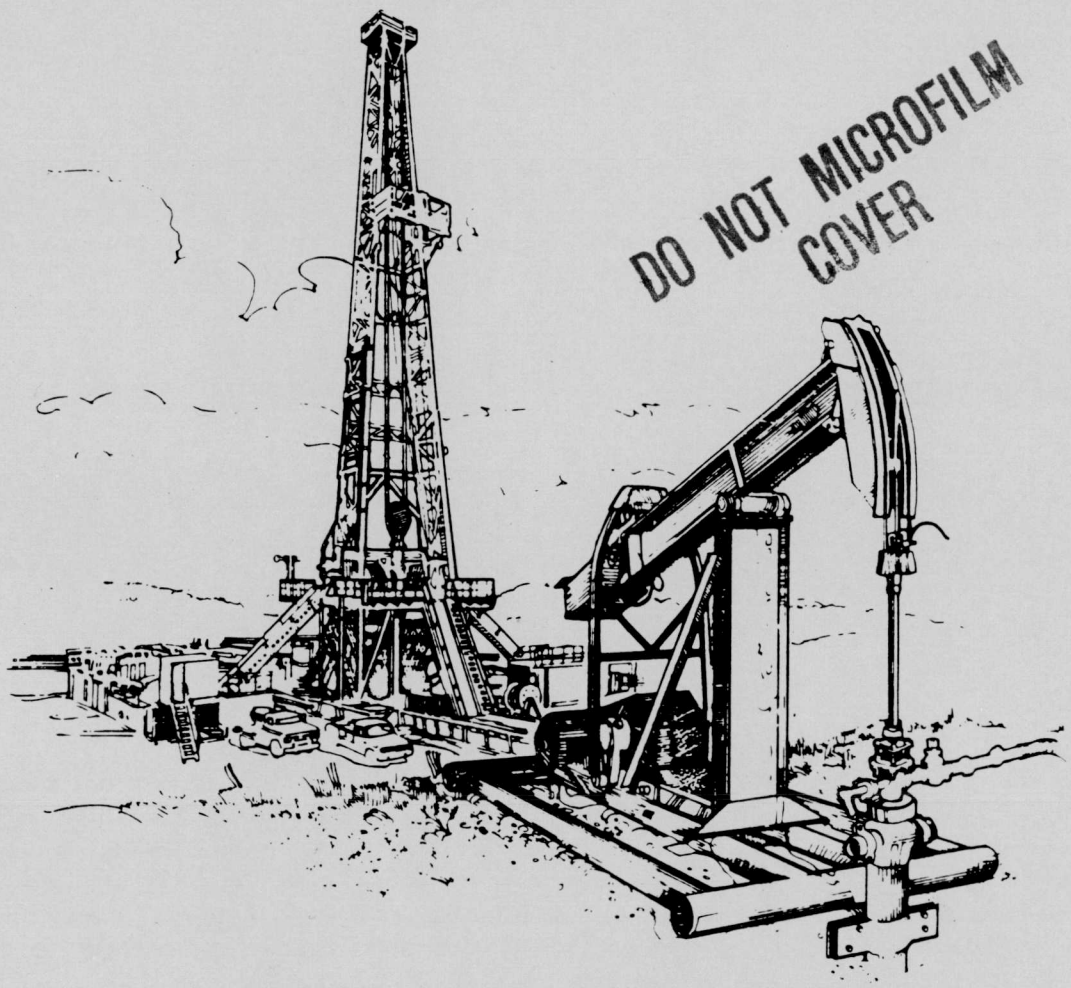
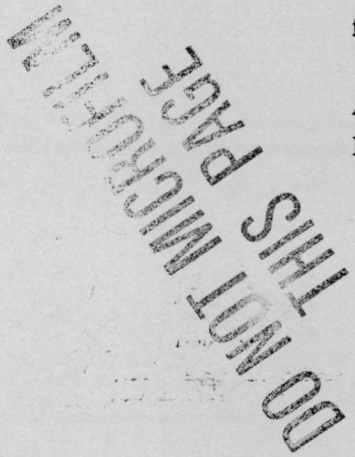
BARTLESVILLE PROJECT OFFICE
FY 1989 ANNUAL REPORT



U. S. Department of Energy
Office of Fossil Energy
April 1990



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BARTLESVILLE PROJECT OFFICE FY 1989 ANNUAL REPORT

APRIL 1990

Prepared for
U. S. Department of Energy
Assistant Secretary for Fossil Energy

Prepared by
Bartlesville Project Office
P. O. Box 1398
Bartlesville, OK 74005

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ABBREVIATIONS

AEPT	Advanced Extraction and Process Technology
BPD	Barrels per day
BPO	Bartlesville Project Office
CAT	Computerized axial tomography
EOR	Enhanced Oil Recovery
FE	Office of Fossil Energy, U.S. Department of Energy
ERAB	Energy Research Advisory Board
IOCC	Interstate Oil Compact Commission
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory, University of California
LLNL	Lawrence Livermore National Laboratory
MEOR	Microbial Enhanced Oil Recovery
MOU	Memorandum of Understanding
NAS	National Academy of Science
NIPER	National Institute for Petroleum and Energy Research
NPC	National Petroleum Council
OER	Office of Energy Research, DOE
OGR	Office of Geoscience Research, DOE
PRDA	Program Research and Development Announcement
SNL	Sandia National Laboratory
SPE	Society of Petroleum Engineers
SUPRI	Stanford University Petroleum Research Institute
TORIS	Tertiary Oil Recovery Information System
UCG	Underground coal gasification

1.0 INTRODUCTION

1.1 BPO MISSION

The Bartlesville Project Office (BPO) was established in 1983 to succeed the Bartlesville Energy Technology Center (BETC). Its lead mission from the Office of Fossil Energy (FE) of the U.S. Department of Energy is to plan and implement research in the Enhanced Oil Recovery (EOR) and Advanced Extraction and Process Technology (AEPT) subprograms of the Petroleum Program. As such, BPO oversees more than 140 research projects falling within these two broad subprograms and support activities. These projects form the major portion of DOE's National Petroleum Research Program, the critical aim of which is to arrest the decline of domestic oil production and to maximize economic recovery. The project funding categories are given in Table 1.

BPO's responsibilities under this mission are to:

- Assist Headquarters (HQ) in program formulation
- Develop and execute implementation plans which advance oil production technology for the currently unrecoverable petroleum resource base
- Develop environmentally acceptable recovery processes and improve fundamental understanding of novel concepts in EOR and geoscience
- Implement cross-cutting geoscience research along with other fundamental chemical, physical, and thermodynamic studies
- Implement EOR/AEPT technology transfer to the scientific and technical user community, especially the independent petroleum operators

The EOR subprogram consists of two categories – Light Oil and Heavy Oil – and includes research activities in: (1) geoscience, (2) chemical flooding, (3) gas flooding, (4) thermal recovery, (5) novel technology, and (6) microbial EOR.

The AEPT subprogram includes research activities in (1) fundamental geoscience and extraction research, (2) supporting technology and environmental research, and (3) university geoscience research.

Table 1 Project Funding Categories

TYPE OF PROJECT	NO. OF PROJECTS	PERCENT
Grants	38	26
Contracts	21	14
FWPs (Pass thru to National Labs)	18	12
PRDA/RFP	6	4
NIPER	49	34
SBIR	5	4
International	8	6
Total	145•	100

• Total does not include three proposed projects with Norway and two with Mexico.

ABBREVIATIONS
FWP - Field Work Proposal
PRDA - Program Research and Development Announcement
RFP - Request for Proposal
NIPER - National Institute for Petroleum and Energy Research
SBIR - Small Business Innovation Research

1.2 ORGANIZATION

As shown in the BPO organization chart (Figure 1), three program coordinators and seven project managers assist the BPO Director. In carrying out BPO's national research responsibilities, the Director reports to the Assistant Secretary for Fossil Energy. In executing BPO's lead mission responsibilities in EOR and AEPT, the Director coordinates programmatic activities with the Deputy Assistant Secretary for Oil, Gas, Shale and Special Technologies and the Deputy Assistant Secretary for Management, Fundamental Research and Cooperative Development (Figure 2).

BPO implements and coordinates its mission through management of research projects performed by:

- The National Institute for Petroleum and Energy Research (NIPER), which utilizes the DOE facilities and laboratory equipment at Bartlesville, Oklahoma
- Energy technology centers and national laboratories
- University and industrial research laboratories
- Joint research projects under cooperative agreements with foreign governments and international organizations

Some research projects are joint efforts with oil-producing states and are executed under Memoranda of Understanding (MOUs) by universities and/or state geological surveys.

1.3 PROGRAM FUNDING

The BPO budget for FY82-90 is shown in Figure 3. The sharp reduction in 1983 reflected the general shift of emphasis away from oil and gas research by the government and coincided with the defederalization of BETC and the advent of BPO and NIPER. The distributions among the three research areas for FY88-90 are as follows (in thousand dollars):

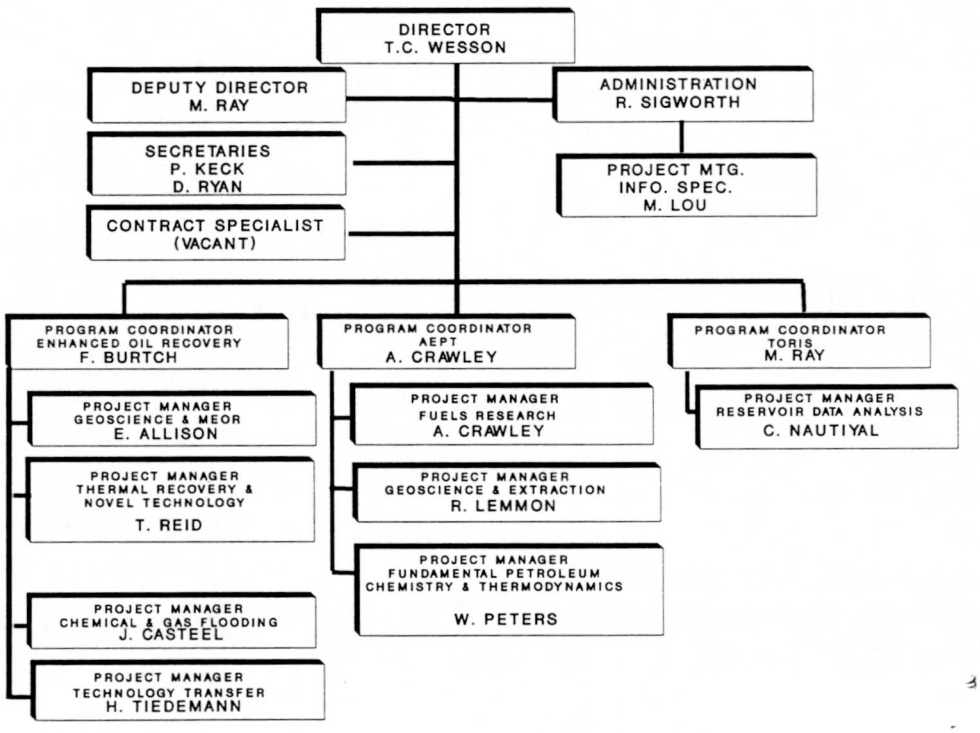


Fig. 1 BPO Organization Chart

Program	FY88	FY89	FY90
Light Oil	9,719	16,738	22,474
Heavy Oil	3,600	4,245	4,014
AEPT	2,992	3,674	3,553
Sub-total	16,311	24,657	30,014

Program	FY88	FY89	FY90
Other Programs and Admin	5,830	4,913	3,010
Total	22,141	29,567	33,051

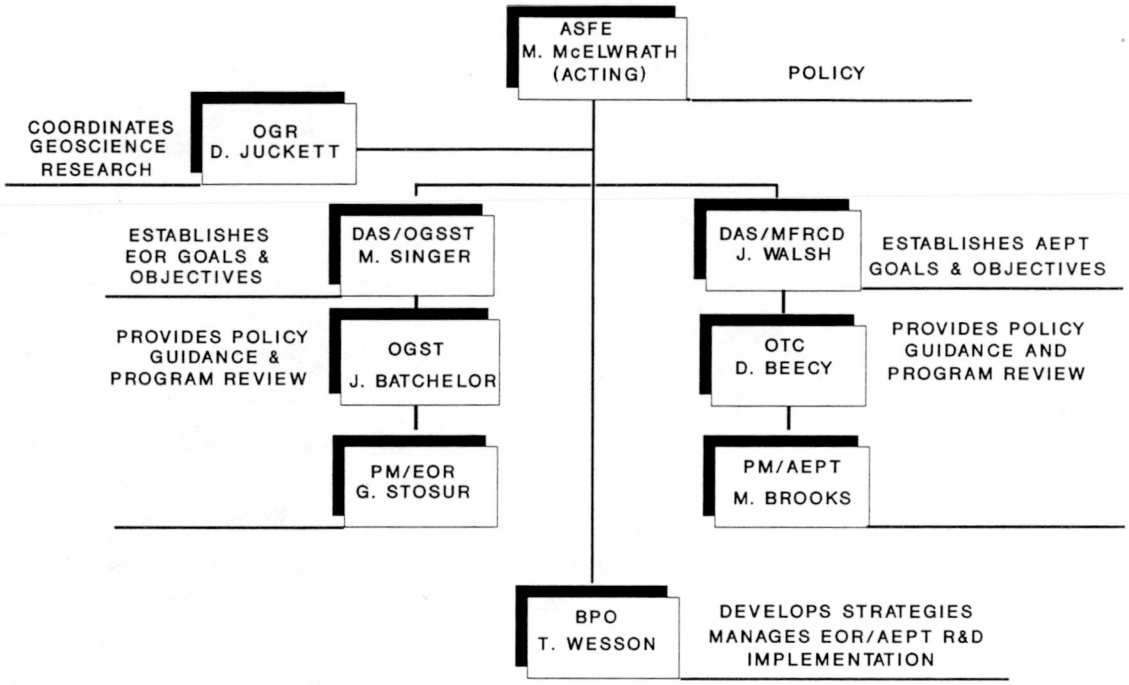


Fig. 2 Organization Supporting Fossil Energy Petroleum R&D

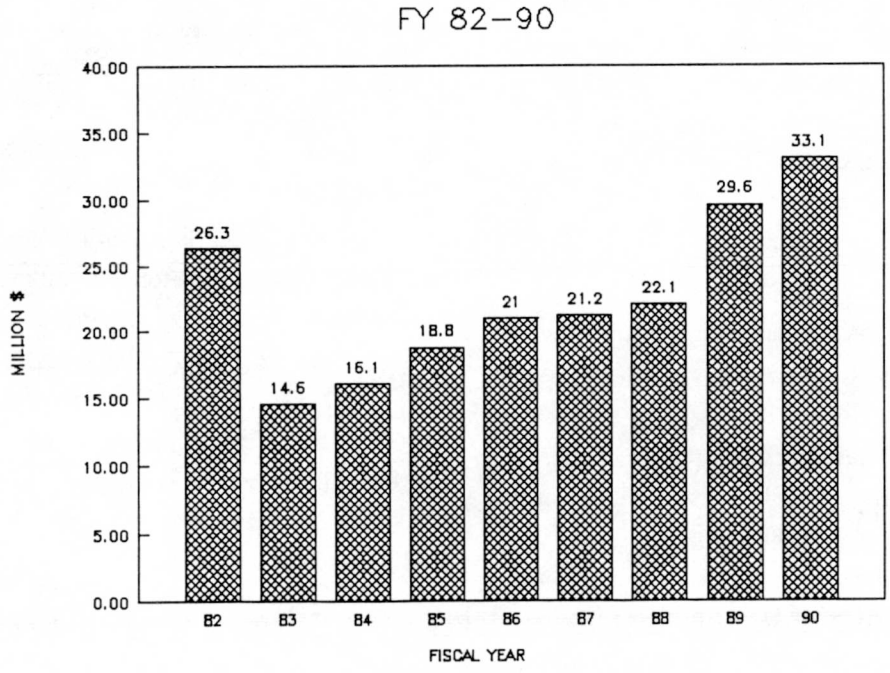


Fig. 3 BPO Budget Summary

2.0 PROGRAM FOCUS & DIRECTION

The Federal Oil Research Program has evolved over the last 15 years, as illustrated in Figure 4. Since the last major revision of the EOR plan in the early eighties, the U.S. oil situation has changed significantly. These changes may be summarized as follows:

1. Domestic and World Oil Markets

Oil prices collapsed in early 1986 (from $26-28 to $10-12 per barrel), but have recovered partially since. In 1989 West Texas Intermediate crude was in the $17-22 range. With U.S. oil production declining again and oil demand rising, oil imports are increasing rapidly. The American Petroleum Institute reports that 1989 imports averaged 7.59 million barrels per day (BPD), accounting for 46% of U.S. oil demand. The domestic production decline has been accompanied by the plugging and abandonment of large numbers of marginal wells, thus denying economic access to an increasingly significant portion of the remaining oil in place.

2. State of the Art

The following concepts have evolved over the last few years and now form the basis of the R&D program.

- Unrecovered mobile oil (UMO) as a major target along with immobile residual oil left in the formation after waterflooding
- Understanding of reservoir heterogeneity as key in designing EOR or UMO projects
- Site-specific focus as key to integrating application- oriented R&D
- Hypothesis that reservoirs of similar geological histories should have similar heterogeneities, and are thus expected to show similar response to a given recovery process.

3. Policy

The Department of Energy is developing a new National Energy Strategy. It is expected that the strategy will confirm the recently evolved concepts of near-, mid- and long-term objectives, and will emphasize technology transfer and environmental protection. Current policy also recognizes the urgency to avoid loss of economic access to the resource by premature abandonment of marginal wells.

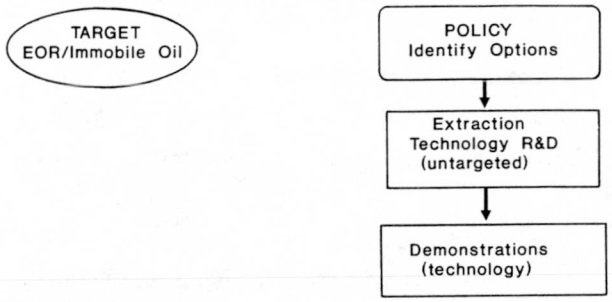
In FY89 emphasis began to shift from long-term, high-risk R&D to maximizing productivity of the remaining oil in place (Figure 5). This refocusing was supported by two initiatives:

1. Enhanced Domestic Oil Production Initiative (August 1988)

The United States is a mature, highly explored petroleum region. Therefore, additional reserves are more likely to result from enhanced recovery of existing resources rather than from major oil discoveries. Thus, the key to producing more oil is a better understanding of the resource, including more detailed reservoir characterization. The objectives were divided into three time frames: near-, mid-, and long-term.

2. Hydrocarbon Geoscience Research Strategy (June 1989)

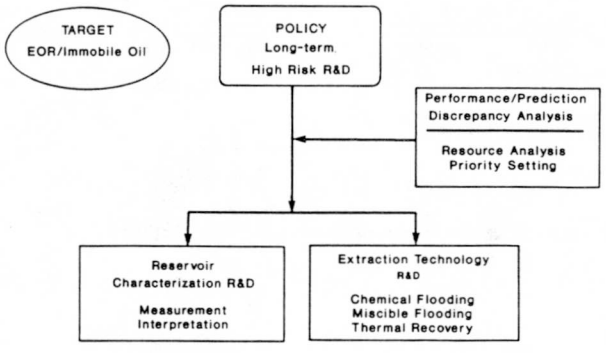
1974: EOR RESEARCH PROGRAM ESTABLISHED



1976-1980

- With the world oil price rise and shortages of 1979-80, EOR was again seen as a major domestic oil source, requiring only economic incentives.
- The Tertiary Incentive Program granted price relief to over 400 projects designed to increase production.
- Research was focused on residual oil and specific EOR techniques.
- Resource Analysis was initiated to identify the most promising types of reservoirs and to estimate overall EOR potential.

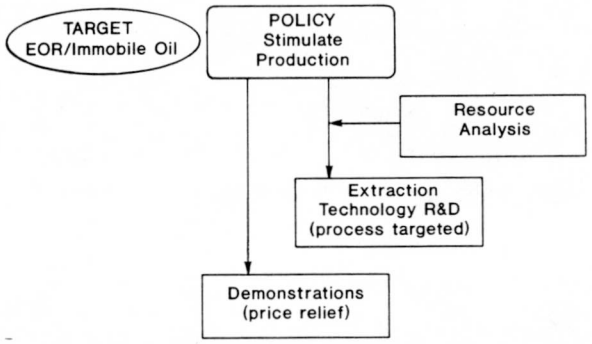
1981-89: TARGET AND SCOPE EXPANDED



1974

- Immediately after the oil embargo of 1973-74, federal EOR research was initiated under the belief that the technology need only be demonstrated to be applied.
- A total of 27 demonstration projects were cost-shared with industry to prove the technology options – with mixed results. Due to limited technical understanding, the reasons for the successes and failures experienced in the field could not be adequately explained.
- Limited engineering research focused on the properties of residual, immobile oil and fundamental EOR extraction mechanisms.

1976-80: RESOURCE ANALYSIS ADDED



1981-1989

- As both cost-shared and price-relief projects failed to produce significant oil, demonstrations were discontinued.
- Recognition that inadequate understanding of reservoir properties contributed greatly to project failures resulted in new reservoir characterization research.
- Discrepancy analysis, comparing predicted to actual project results, became central to technology assessment. Resource analysis was expanded in conjunction with the National Petroleum Council study of the potential of EOR.
- Extraction research retained its long-range fundamental orientation toward immobile oil and EOR.

Fig. 4 Evolution of Federal Oil Research

Goal: To increase significantly the economic producibility of domestic oil and gas resources through geoscience research and related activities.

The objectives are again divided into three time frames, with the research activities are being conducted concurrently, and not in sequence.

a) Near term (Results in anticipated 0-5 years)

- Maintain access to the resources in currently producing domestic oil and gas fields, and decrease the rate of decline of domestic oil production by application of currently available technology
- Develop environmentally sound, economically reversible well plugging techniques.
- Study the environmental impact of advanced extraction processes and establish criteria for effective management of oil-field production wastes.

b) Mid term (Results in anticipated 5-10 years)

- Maximize the recovery of discovered oil and gas through improved understanding of the resource and development of advanced extraction techniques
- Increase efficiency of resource discovery through improved understanding and advanced instrumentation
- Expand environmental understanding to keep pace with advances in extraction technology

c) Long term (Results anticipated in more than 10 years)

- Improve the fundamental understanding of the oil and gas resource and the chemical, physical and biological phenomena that govern its occurrence and recovery and the environmental impacts of its use
- Support the community of scientists and researchers in the field of oil and gas discovery and recovery by providing research and training opportunities

Relevant elements of the Hydrocarbon Geoscience Research Strategy are incorporated in the plans for FY90-95.

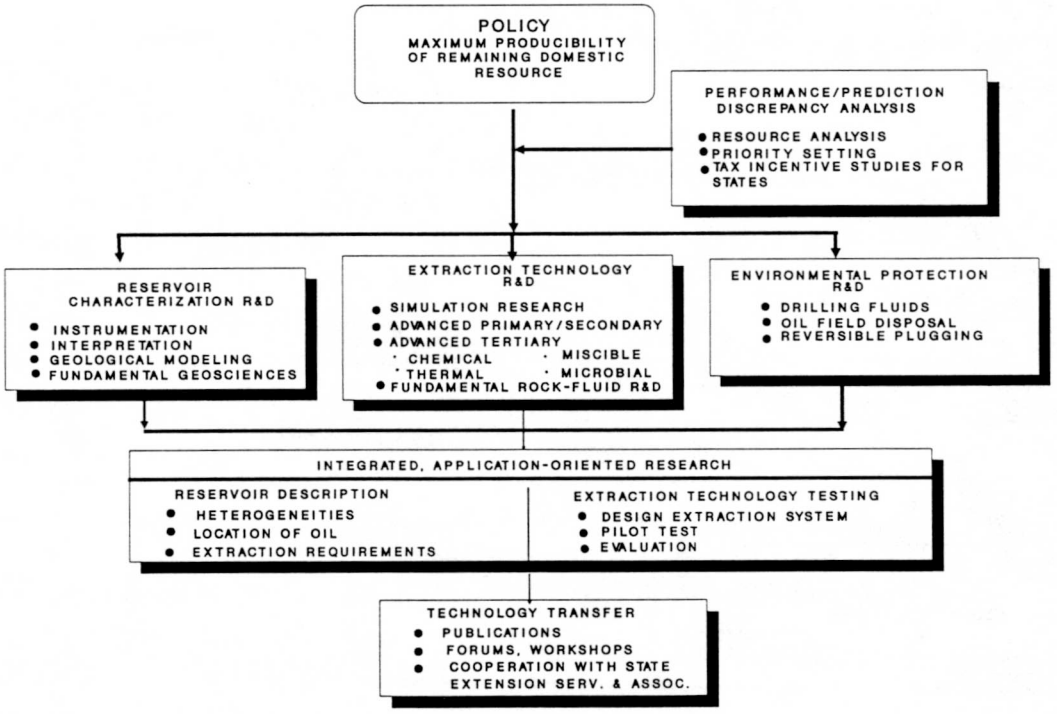


Fig. 5 Federal Oil Research Program

3.0 RESEARCH ACTIVITIES AND ACHIEVEMENTS

BPO is responsible to the DOE Office of Fossil Energy for the management of over 140 research projects conducted at NIPER, METC, national laboratories, universities and industry, and for overseeing joint projects with other countries under international agreements. This research effort falls into two broad subprograms.

1. Enhanced Oil Recovery (EOR) subprogram, executed under the Light Oil and Heavy Oil Enhanced Recovery Program Implementation Plans (PIPs).

2. Advanced Extraction and Process Technology (AEPT) subprogram, executed under the AEPT Program Implementation Plan (PIP).

Common elements of both subprograms are:

- Emphasis on geoscience research in resource assessment and reservoir characterization
- Tertiary Oil Recovery Information System (TORIS) analytical capabilities
- Technology transfer to industry

3.1 EOR SUBPROGRAM

The work breakdown structure and the logic of the EOR research program are shown in Figures 6 and 7. The major program activities in FY89 were:

- Continued cooperative research projects in reservoir characterization, mainly through state Memoranda of Understanding (MOUs).
- Initiated the National Laboratory/industry cooperative R&D program (Sandia and Los Alamos).
- Initiated field-project research in horizontal wells in California and Oklahoma, in measuring wellbore heat losses during steam flooding in California, and in oil mining in Louisiana.
- Provided direction for fundamental research in EOR processes.
- Provided technical support to the Office of Geoscience Research in developing integrated, cross-cutting, geoscience strategy.

Significant achievements of research activities in FY89 are summarized under each of six EOR activities: geoscience, chemical flooding, gas flooding, thermal recovery, novel technology and microbial EOR.

For many years DOE supported R&D and field testing of miscible CO_2 flooding in light-oil reservoirs and steam flooding in heavy-oil reservoirs. Both techniques are now applied in the field as commercial processes. Thus, in these two processes oil companies are now conducting only applied research, mainly to solve field problems as they arise. DOE has continued to fund R&D to improve reservoir characterization and sweep efficiency, and hence oil recovery. Research in chemical flooding, for which there is an enormous oil potential, was funded at a high level by both industry and DOE for many years. But since 1986 oil companies have severely curtailed their research activity in this area, leaving the govern-

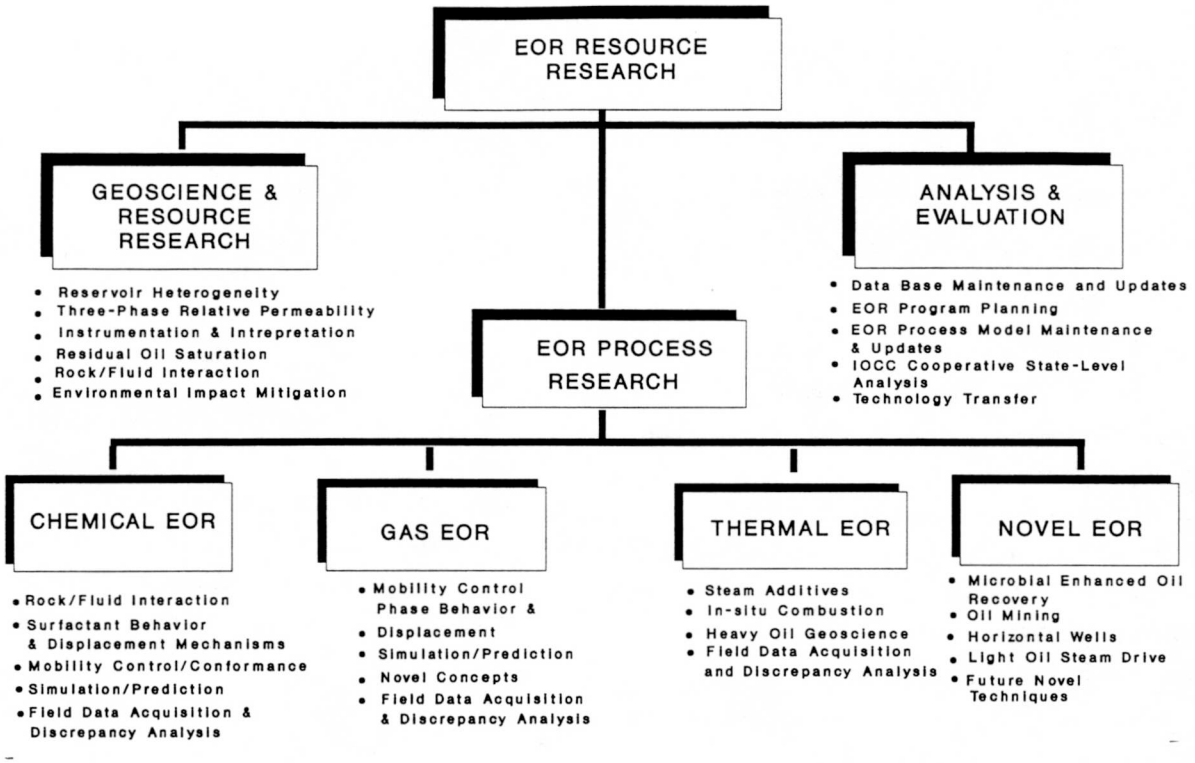


Fig. 6 Work Breakdown Structure -- EOR Subprogram

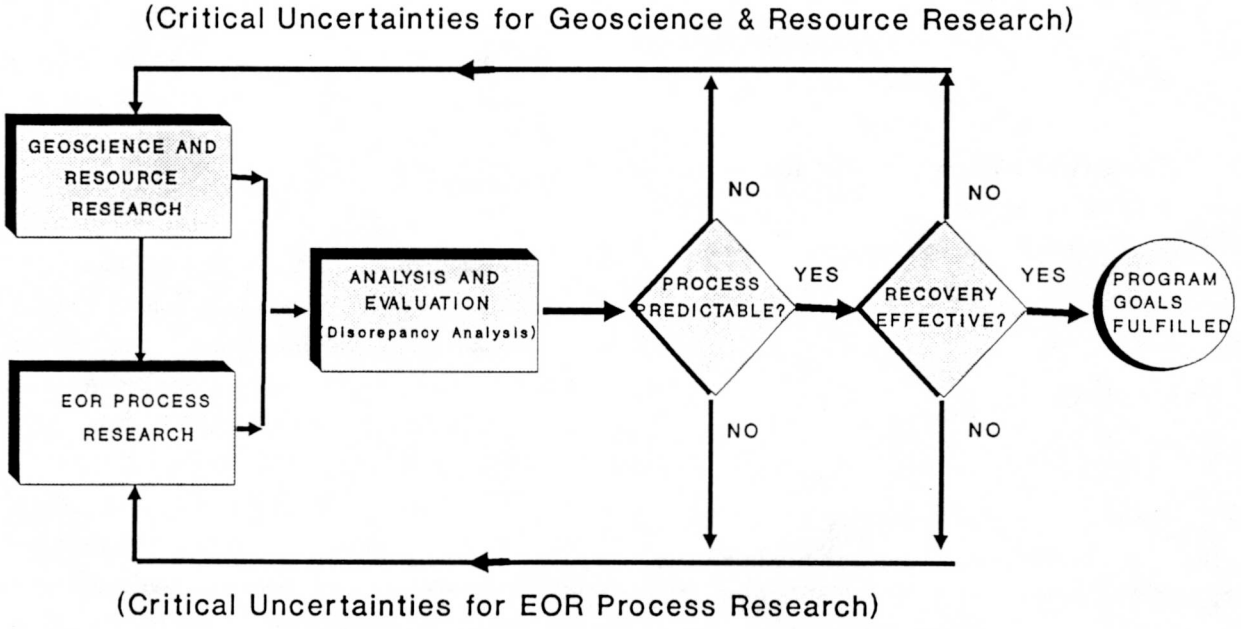


Fig. 7 Logic of the EOR Research Subprogram

ment as the main source of funding.

In 1988 EOR production in the U.S. was about 718,000 BPD, or 8.8% of total crude oil production (8,270,000 BPD). The contribution of the different EOR processes was as follows: (Figures based largely on the Oil & Gas Journal (OGJ) 1988 EOR Survey (April 18, 1988, p. 46), except for steam injection. The OGJ attributes 455,500 BPD to this process, but the Review of California Oil & Gas Production, issued by the Conservation Committee of the California Oil Producers, shows 520,000 BPD for California alone. The main difference is due to the fact that the OGJ survey is based largely on the 1987 figures.

Thermal	
Steam	540,000 BPD
In situ combustion	5,500
	545,500
Chemical	
Polymer	21,000
Micellar-polymer	1,500
	22,500
Gases	
Miscible CO_2	65,000
Hydrocarbon gases	26,000
Nitrogen & flue gases	59,000
	150,000
Total	718,000

It is clear from the preceding table that steam injection is the dominant EOR method, accounting for 76% of the total. For light oil, CO_2 injection is the largest contributor with 9% of the total.

3.1.1 Geoscience

Within the EOR subprogram, geoscience research is focused on improved understanding and predictability of reservoir rock properties that constrain production and the effectiveness of EOR processes. Rock heterogeneities that impact production occur at all scales, from within single pores (millimeters) to between fields (tens of kilometers). A significant portion of the geoscience activity is focused at the interwell scale (hundreds of meters) in known fields. This research has the potential to increase production of mobile oil, at current oil prices in the near to mid term, through targeted infill drilling and more efficient waterflood and EOR technologies.

The objectives of this activity are to:

- Apply currently available technology to characterize known reservoirs for increased recovery (near-term research)
- Improve understanding of reservoir heterogeneities and their effect on fluid flow in the reservoir, especially at the interwell scale (mid-term research)
- Develop instrumentation for measuring reservoir rock and fluid properties and develop analytical and modeling techniques to design and interpret the measurements (mid-term research)
- Improve fundamental understanding of reservoir phenomena applicable to improved hydrocarbon recovery (long-term research)

In FY89 substantial progress was made in two geoscience areas: (1) development of techniques to measure reservoir rock properties in situ, and (2) development of methodologies to predict the probable variation in reservoir properties between wells, based on analogous outcrop and subsurface geologic units. The following research projects illustrate the progress made.

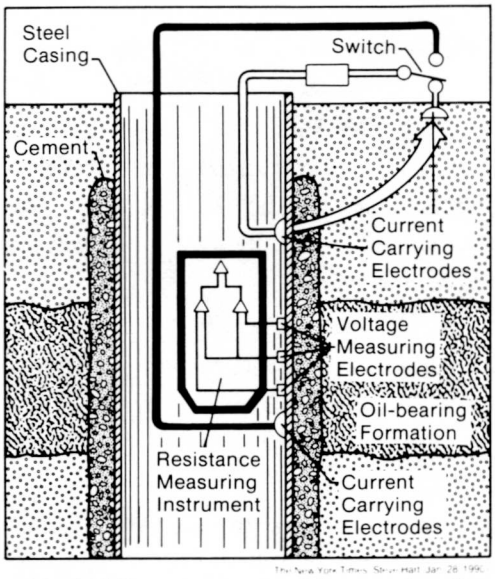
3.1.1.1 Resistivity Measurement in Cased Wells

Contractor: ParaMagnetic Logging, Inc.

A resistivity logging device has been designed and built to measure the electric resistivity of geologic formations behind the well casing. The measurement is equivalent in accuracy to the conventional, open-hole laterolog, and is more accurate than the thermal neutron log (TDT) for determining water saturation. The test measurements show promise for interpreting the presence of water or oil in old wells, and for locating by-passed oil. Additional work will be necessary to enable the device to make continuous measurements while being moved through the wellbore, thereby improving the cost-effectiveness of the tech-

nique.

Publications: News articles about this project appeared in many technical and news publications.



Resistivity measurement in cased wells
ParaMagnetic Logging, Inc.

3.1.1.2 Predicting Reservoir Variation

Contractor: National Institute for Petroleum and Energy Research (NIPER)

Barrier island reservoirs and outcrops of the Lower Cretaceous Muddy formation were studied. A predictive model of reservoir heterogeneities based on subsurface geologic and engineering data was developed. The research has also resulted in a methodology for evaluating reservoir heterogeneities. This methodology is contained in an expert system for use on personal computers. After further development, this system will be made available to industry.

The study showed that depositional heterogeneities, which are generally the largest scale, are the most predictable in barrier island reservoirs. Medium- and small-scale heterogeneities related to diagenesis and faulting are the least predictable. Depositional heterogeneities have more impact on the success of primary (including infill drilling) recoveries. Diagenetic and structural heterogeneities have more influence on secondary and tertiary recovery projects. This methodology is useful in developing plans for optimizing oil recovery from a given reservoir and in evaluating similar reservoirs.

Publications: Two DOE reports, four papers and one technical meeting poster presentation. (DOE reports are listed in Appendix B.)

3.1.1.3 Modeling Reservoir Heterogeneity

Contractors: University of Texas at Austin, New Mexico Institute of Mining and Technology (NMIMT)

In two research projects, "Geoscience Studies with a Focus on Reservoir Heterogeneity" and "Systematic Procedure for Reservoir Characterization", numerical descriptions of interwell-scale reservoir heterogeneity are being developed. Equations and numerical methods for a predictive model have been developed to represent both the statistical variation and measurement uncertainty of reservoir heterogeneity. The data obtained can be used in reservoir simulation.

Geostatistical analyses of both studies are based on detailed permeability measurements of outcropping reservoir analogues. The results of these analyses will improve the predictability of EOR projects and infill drilling by making numerical simulations more representative of reservoir architecture.

Publications: University of Texas published eight papers and NMIMT published two.

3.1.2 Chemical Flooding

Vast amounts of immobile oil left in most reservoirs after waterflooding are prime candidates for recovery by surfactants, if economic micellar formulations can be found for various reservoir conditions.

The goals of this activity are to:

- Extend the application range of chemical flooding methods to reservoirs with higher salinity, hardness, temperature and oil viscosity.

- Increase understanding of the mechanism and effectiveness of injected fluids to overcome viscous and capillary forces that retain immobile oil.
- Develop methods to increase the productive life of marginal wells, and assess the economics of field-scale applications.

The following are some of the significant accomplishments in FY89.

3.1.2.1 Adsorption Studies of Surfactants

Contractors: NIPER and Columbia University

Adsorption, phase trapping and precipitation of surfactants in reservoirs are major factors governing the success or failure of a surfactant flood. Significant progress has been made in obtaining comparative surfactant adsorption data from flowing (dynamic) experiments, using both crushed and consolidated reservoir cores. Comparison of adsorption results will allow the expansion of the database of surfactant structure, temperature, salinity, rock type, and wettability. The database has widespread potential for initial screening of surfactants for use in a particular reservoir.

Publications: NIPER published four DOE reports, two papers and made one presentation. Columbia University published one DOE report, seven papers, one MS thesis and one PhD dissertation.

3.1.2.2 Contribution to Microemulsion Microstructure

Contractor: University of Minnesota

A new fluid microstructure transition was discovered in mid-range microemulsions. With increasing temperature, some mid-range microemulsions of equal oil and water volumes go abruptly from a water-continuous phase of swollen micelles to bi-continuous phase. The transition has been shown to occur in microemulsions of ionic as well as nonionic surfactants. The microscopy technique was further strengthened by progress in photographic image enhancement and in the making of porous polymer films for sample mounting.

Basic understanding of the mechanism of micelle formation and properties, e.g., viscosity, will help in designing chemical systems that increase oil recovery.

Professors L.E. Scriven and H. Ted Davis of the University of Minnesota, whose EOR research is supported by DOE through BPO, were honored for their achievements in 1989. Dr. Scriven received the American Chemical Society's E.V. Murphree Award and Dr. Davis was elected to the National Academy of Engineering.

3.1.2.3 Development of an Interfacial Activity Model

Contractor: Illinois Institute of Technology

An improved interfacial activity model has been developed to relate interfacial tension (IFT) to composition. The model accounts for the formation of micelles in both the aqueous and oleic phases, as well as nonidealities of the bulk phases. A new dynamic interfacial tensiometer has been developed to determine IFT at liquid-liquid interfaces at high rates of interfacial expansion. With a validated model it will not be necessary to test every surfactant compound.

Dr. Darsh T. Wasan of the Illinois Institute of Technology received the Ernest W. Thiele Award of the American Institute of Chemical Engineers. DOE has partially supported Dr. Wasan's project on improved alkaline flooding and foaming agents for mobility control.

Publications: One DOE report, eight papers and one MS thesis.

3.1.3 Gas Flooding

In 1988 gas flooding, excluding gas injected strictly for pressure maintenance, contributed 150,000 BPD of oil production. Of this, miscible CO_2 injection accounted for 65,000 BPD, making it the principal EOR method for light oil.

The main objective of this research activity is to improve volumetric sweep efficiency and/or reser-

voir conformance. A specific objective is to increase understanding and effectiveness of agents (foams and gels) and processes that reduce permeability contrast and/or control mobility of injected fluids.

3.1.3.1 Development of High-Pressure Crystal Viscometer

Contractor: New Mexico Institute of Mining & Technology

A viscometer, based on an oscillating quartz crystal, was developed, tested, and installed in a continuous multiple-contact apparatus. This is one of the first instruments which can measure the viscosity of CO_2-oil mixtures at dynamic reservoir conditions. Because this system operates continuously, phase equilibrium data can be generated faster than with a static-equilibrium cell. Thus, the apparatus can now simultaneously measure viscosity, density, and composition of flowing phases. The data generated are used to improve simulation of field projects of CO_2 injection.

Publications: Two papers

3.1.3.2 Entrainers for Carbon Dioxide Sweep Improvement

Contractor: NIPER

Entrainers are CO_2 additives (surfactants, hydrocarbons, other organic compounds, polymers, etc.) which increase the CO_2 viscosity without reducing its oil-displacing ability. This project is important because increasing the CO_2 viscosity improves the unfavorable CO_2/oil viscosity ratio and results in higher sweep efficiency.

Entrainer-enhanced CO_2 displacement has been tested successfully. Some cosolvents were found that can enhance CO_2-extracting power and significantly increase the viscosity of the CO_2 phase.

Publications: Two DOE reports, one paper and two presentations.

3.1.4 Thermal Recovery

In 1988 U.S. oil production by thermal methods was about 545,500 BPD. Some heavy oil is also produced by primary recovery and by waterflooding. Total heavy oil production in the U.S. is about 950,000 BPD, mostly from California. By far the main thermal recovery method is steam injection (both steam flooding and steam cycling) accounting for about 540,000 BPD in 1988, compared with only 5,500 by in-situ combustion. (see Table in Section 3.1)

The primary objective of the Heavy Oil Enhanced Recovery category is to maximize the economic producibility of the U.S. heavy oil resource by overcoming technical and economic constraints on production. Specific objectives are:

- Increase predictability of reservoir performance of heavy oil processes through improved understanding of fundamental recovery mechanisms at reservoir conditions and through improved reservoir description.
- Improve the recovery efficiency of thermal-recovery processes by determining the most suitable recovery mechanisms for each set of reservoir properties and the range of application of chemical additives for increasing mobility control and volumetric sweep efficiency.
- Extend the range of application of thermal processes to thinner, deeper, and more heterogeneous reservoirs.
- Assess the technical viability for additional economic recovery of heavy oil by novel and other processes not presently in extensive use in heavy oil recovery.

The following are some of the more significant research accomplishments in FY89.

3.1.4.1 Reservoir Flow Properties

Contractor: Stanford University Petroleum Research Institute (SUPRI)

A surplus medical computerized axial tomography (CAT) scanner was installed with a workstation and necessary interpretation software. The scanner is being operated routinely to measure two-phase saturations and to test sand-pack homogeneity.

The advantage of this technique is the visual depiction of the flow paths in a porous medium.

Publications: SUPRI published eight papers and eight DOE reports on this and other research projects conducted in FY89.

3.1.4.2 Mechanisms of Mobility Control with Foams

Contractor: Lawrence Berkeley Laboratory (LBL), University of California

The goal of this research is to define the pore-level mechanisms which determine the design criteria of successful application of foam in steamfloods. Experimental work indicates that the following factors are important:

- Stability of the liquid films, separating foam bubbles and trapped oil blobs, controls the foam stability.
- Flow of trains of surfactant-laden gas bubbles through capillaries is an important ingredient of foam transport in porous media.
- Bubble size (texture) affects flow resistance, with fine bubbles imparting large flow resistance.

Results of this research can be used in improving design of steamflood projects.

Publications: LBL published five papers and one DOE report on FY89 research

3.1.4.3 Sensing Methods for Thermal EOR

Contractor: Lawrence Livermore National Laboratory (LLNL)

The objective is to develop new field methods for monitoring in-situ changes in the formation during thermal EOR operations.

- Numerical simulation of cross-borehole electromagnetic (EM) experiments in the field showed a significant EM signal feature due to steam injection. The steam-invaded zone could be delineated from cross-borehole measurements. This is important in the study of volumetric sweep efficiency and steam override.
- A borehole EM transmitter was designed and constructed to transmit signals up to 100 m (330 ft) from the well with a frequency range of 250 to 20,000 hz. This extended the radius of investigation from 10 m (33 ft) in previous EM transmitters to 330 ft, which is about the interwell distance in the more closely spaced steamflood projects.
- A computer-controlled, cross-borehole EM system for thermal-front mapping was assembled, tested and then deployed in the South Belridge Field, California, on a steamflooded Mobil lease. While the data are still being processed and interpreted, preliminary results appear promising.

Publications: Three papers

3.1.5 Novel Recovery Technology

The R&D objectives of this activity are:

- Identify and assess the feasibility of novel extraction technologies by literature search, laboratory tests, numerical simulation, and by soliciting proposals from industry and the research community.
- Demonstrate technology applications and assess process economics and environmental acceptability through cost-shared field tests.
- Transfer the technology to industry.

Two contracts for novel EOR technology were awarded in FY89.

3.1.5.1 Underground Mining

Contractor: Improved Gravity Drainage Company (IGD)

The purpose is to develop and demonstrate an underground mining approach to access shallow, low-pressure reservoirs via shaft entries and underground drilling and production rooms. The oil will be drained by gravity into inclined and horizontal wells. The oil reservoir selected for this cost-shared project is the Annona Chalk in the Caddo Pine Island field, Louisiana. The environmental assessment study is nearly completed and other preparatory work is under way.

3.1.5.2 Horizontal Drilling

Contractor: Rougeot Oil & Gas Company

Horizontal wells provide access to more reservoir rock where reservoir geometry and properties are suitable. Production rates are typically three times those of vertical wells. The technique is being widely used by major oil companies and large independents, but not by small independents.

In a cost-shared project, a horizontal well will be drilled in the Bartlesville sand of the North Flatrock field, Osage County, Oklahoma. Production data will be compared with vertical wells in the reservoir. In this area the Bartlesville sand is about 1300 ft deep, is underlain by an aquifer, and has not been waterflooded. The environmental assessment study is complete and other preparatory work is under way. Drilling should start in the first half of 1990.

3.1.6 Microbial EOR

The objectives of the microbial EOR (MEOR) activity are to:

- Identify and develop microbial extraction concepts and technology requirements
- Examine metabolic and biochemical characteristics of microbes for:
  - In-situ generation of surfactants, polymers and solvents
  - Selective permeability alteration
  - Wettability alteration
  - Other rock/fluid modifications
  - Reducing production of H2S dissolved in the reservoir oil
- Conduct controlled field tests to determine incremental recovery due to the MEOR process, and to assess the process efficiency, economics and environmental impact.

Laboratory and field research has demonstrated the use of microorganisms to recover more incremental oil from depleted reservoirs. Gases, surfactants, polymers, acids and alcohols are products of microbial metabolism. Improved recovery is attributed to some of these products and to their interactions with reservoir rocks and fluids. Field tests have mostly been single-well stimulation treatments, and a few microbial-enhanced waterfloods.

MEOR has had a long history of use in mature oil fields where improved production is difficult to document. As a result of this lack of scientific rigor, the ability of MEOR to recover incremental oil has not been quantitatively demonstrated. Therefore, recent emphasis has been on designing microbial systems and documenting their actual behavior to understand the processes that result in increased oil production.

3.1.6.1 Influence of Bacteria on Increased Oil Recovery

Contractor: NIPER

Using a mixed culture of sugar-fermenting bacteria (molasses added as nutrient), researchers showed that improved oil recovery from waterflooded cores depended on the presence of the microbes in the core, probably at the oil-water interface. This incremental recovery could not be duplicated by the bio-products alone without the microbes. This mixed microbial culture produces primarily surfactants. Results of this research will be discussed at the International MEOR Symposium in May 1990.

Publications: Three papers.

3.1.6.2 Microbial Modification of Crude Oil

Contractor: Brookhaven National Laboratory

Oil-degrading microbes use the oil as an energy source to produce gas solvents which improve oil recovery. A major research goal is to understand the chemical degradations that these microbes bring about. Oil/bacteria interactions also need to be understood to mitigate detrimental microbial behavior such as H_2S production and degradation of light oil components. In this area significant progress has been made in demonstrating that selected thermophilic microbes modify both the light and heavy components of crude oils. The oil-consuming microbes produce acids that help emulsify oils. In addition, these experiments have shown that anaerobic thermophilic microbes, which use oil as

their energy source, remove sulfur from the oil without producing H_2S, a distinct environmental advantage

Publications: One DOE report and two papers

3.1.6.3 MEOR Waterflood Field Test

Contractor: NIPER, Microbial Systems Corp. and INJECTECH, Inc.

A field project sponsored by DOE, Microbial Systems Corporation and INJECTECH, Inc., was conducted in cooperation with NIPER. The purpose of the project, started in October 1986, was to determine if injection of a microbial formulation could increase oil production in a mature waterflood. The pilot area selected was in the Mink Unit of Delaware-Childers field in Nowata County, OK, and consisted of four adjacent inverted 5-spot patterns drilled on 5-acre spacing. Baseline data were collected between October 1986 and March 1987. Several microbial formulations were then tested in the laboratory (on Berea sandstone cores) and in the field. Oil production from the unit increased by 13 percent. Key factors identified from the test as important to the design of an MEOR project are fluid-flow patterns and microbial compatibility with reservoir conditions.

Publications: One DOE report and one paper.

3.2 AEPT SUBPROGRAM

Figure 8 shows the work breakdown structure of the Advanced Extraction and Process Technology (AEPT) research subprogram.

The objectives of the AEPT subprogram are to:

- Ensure that fundamental R&D needs of oil, gas, oil shale, tar sands and underground coal gasification (UCG) are appropriately addressed in an environmentally acceptable manner.

Coreflooding experiment to determine oil recovery by microbial-enhanced waterflooding – National Institute for Petroleum and Energy Research

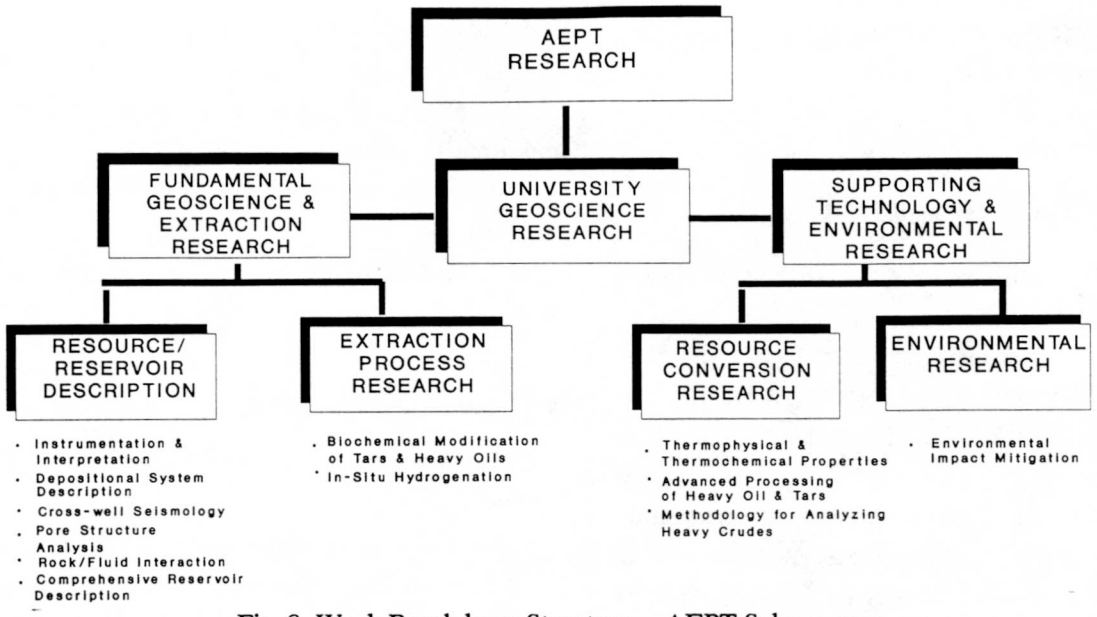


Fig. 8 Work Breakdown Structure -- AEPT Subprogram

- Perform cross-cutting geoscience research to develop technology to quantify reservoir parameters and to evaluate extraction processes. Transfer this technology as it is developed to petroleum producers.
- Perform R&D to develop: (1) procedures for characterizing alternative feedstocks to produce high-quality fuels, and (2) thermodynamic data essential to fuel production.
- Perform R&D toward developing new extraction technologies.

An analysis of the AEPT subprogram was undertaken in 1988. To determine fundamental geoscience needs, over a thousand recommendations from thirty expert panels (NPC, ERAB, NAS, FE and OER program review) were compiled into a framework for analysis.

The number and diversity of these recommendations inhibited the systematic use of all of them in developing the Fossil Energy (FE) fundamental and exploratory research program. They were organized into 48 research areas which were then ranked by DOE officials from BPO and HQ. Ongoing FE research projects and proposed projects were catalogued and matched against the ranked recommendations to form a data base for subsequent planning. Finally, a preliminary assessment was made of priority fundamental and exploratory research areas that apply collectively to oil, gas, tar sands, oil shale and UCG.

A study titled "An Assessment of Fundamental and Exploratory Research Needs for Oil, Natural Gas, Tar Sands, Oil Shale and UCG" was issued in two volumes in November 1988 by the DOE Office of Technical Coordination and BPO. As a result of this study, the subprogram was restructured and partially implemented in FY89. Significant achievements of research activities in FY89 are summarized under each of three activities: (1) fundamental geoscience and extraction research, (2) supporting technology and environmental research, and (3) university geoscience research.

3.2.1 Fundamental Geoscience and Extraction Research

This activity comprises two main elements: (1) reservoir property measurements and characterization, and (2) novel processing technology. In FY89 a downhole seismology project was started, five research projects continued, and 10 research

proposals were selected for award under a fundamental geoscience PRDA. The following are some of the significant research accomplishments in FY89.

3.2.1.1 Reservoir Imaging: Pore Structure Analysis of Reservoir Rocks

Contractor: NIPER

The objective of this project is to use image analysis to measure reservoir rock properties, such as porosity, permeability and capillary pressure, using limited core material. The development of this technique will lead to a new method of reservoir characterization. Renewed interest in relating fluid flow to pore morphology coincided with the development of computer-assisted petrographic image analysis (PIA) using the scanning electron microscope (SEM).

Progress in FY89 included improvements in image quality, computer hardware and software, permeability prediction and fractal studies (for spatial interpolation). Another reservoir imaging technique used was nuclear magnetic resonance (NMR) to study the feasibility of imaging fluid distribution at both the microscopic and macroscopic scales.

In July 1989 a CAT scanner was purchased from a local hospital to enable researchers to study the internal structure of reservoir core samples.

Publications: Four DOE Reports

3.2.1.2 Geodiagnostics for Fossil Energy Recovery

Contractor: Sandia National Laboratory (SNL)

This project started in FY87. Its goal is to develop instrumentation concepts for mapping fluid movement associated with in-situ processing, and for locating significant reservoir heterogeneities. Efforts to date have been to design, construct and test a geoelectric simulation facility (GSF) that lessens the effects of boundary conditions. Boundary effects have been reduced to below instrument sensitivity. The FY90 effort will utilize the GSF, together with field measurements from the EOR program, to determine the validity of using surface electropotential (SEP) to monitor slow processes, such as steamflooding.

Publications: Two Papers

3.2.1. 3 Oil Recovery Technology Partnership

The Partnership includes DOE, Los Alamos and Sandia National Laboratories, and the petroleum industry (Section 5.1). In FY89 the Partnership started a project in cross-well seismology in two parts. One involves the use of existing instrumentation to map (produce an image of) a fault in an unconsolidated sand in the McKittrick field , California (Los Alamos/Chevron, Texaco, Exxon/Stanford University). The other is to develop a 3-component, multi- station, downhole, high-frequency, seismic receiver (Sandia/ Chevron).

3.2.2 Supporting Technology and Environmental Research

This activity consisted of three projects in FY89.

3.2.2.1 Analytical Methodology for Heavy Crudes

Contractor: NIPER

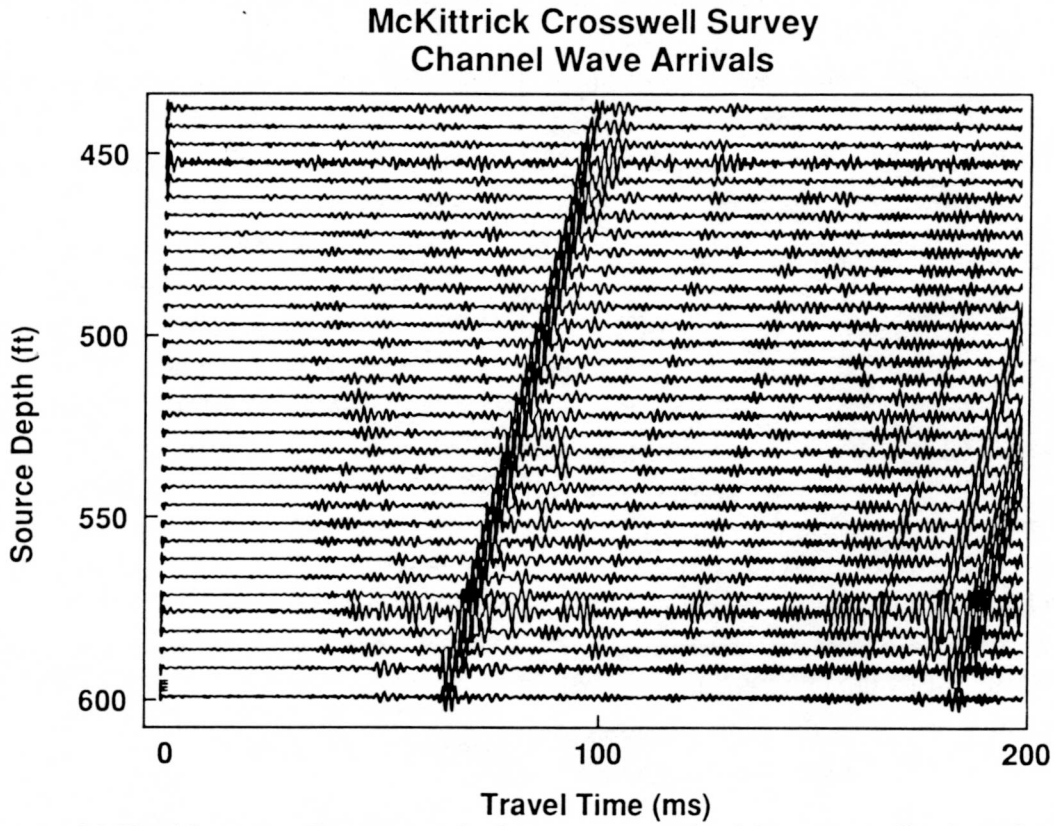
This project started in 1980 when a complex,heavy, Venezuelan crude oil was selected for use in developing new analytical methods to obtain the detailed composition of heavy crudes. The last two chapters of a book, just published, were released in FY89. This book, entitled "Analysis of Heavy Oils: Method Development and Application to Cerro Negro Heavy Petroleum," describes the most exhaustive analysis of a specific heavy petroleum that has ever been done. This analytical work has shown that heavy crudes have extremely complex compositions and over a million individual compounds, many of which are isomers. Future work will concentrate on improving the analytical methods developed and the quality of analytical data obtained.

Publications: Three DOE reports

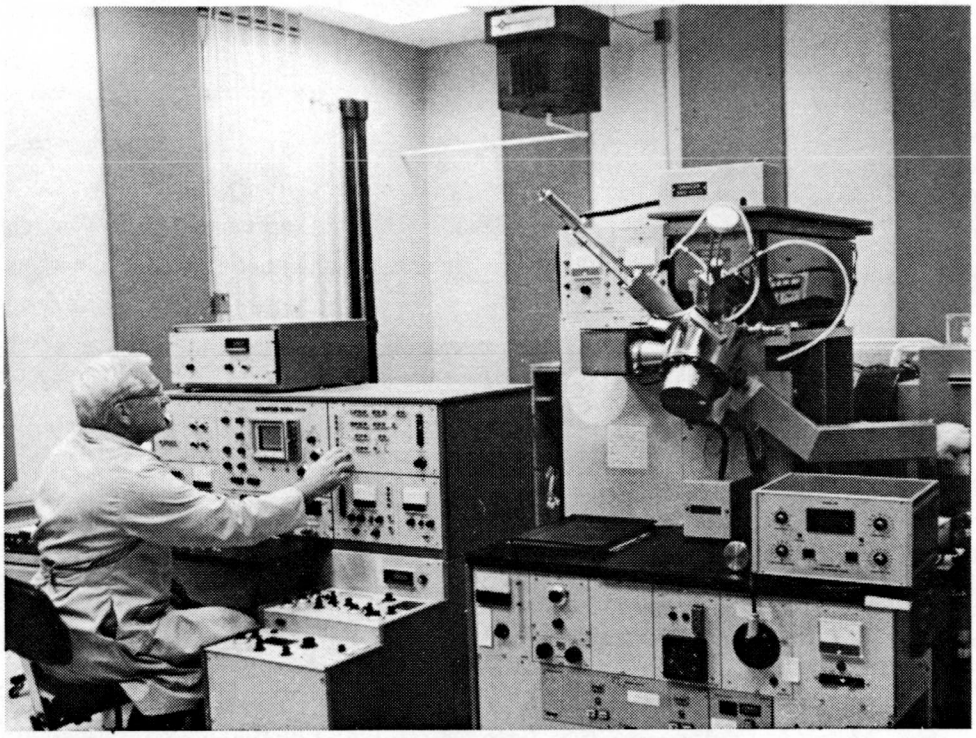
3.2.2.2 Thermodynamics of Heteroatom Compounds

Contractor: NIPER

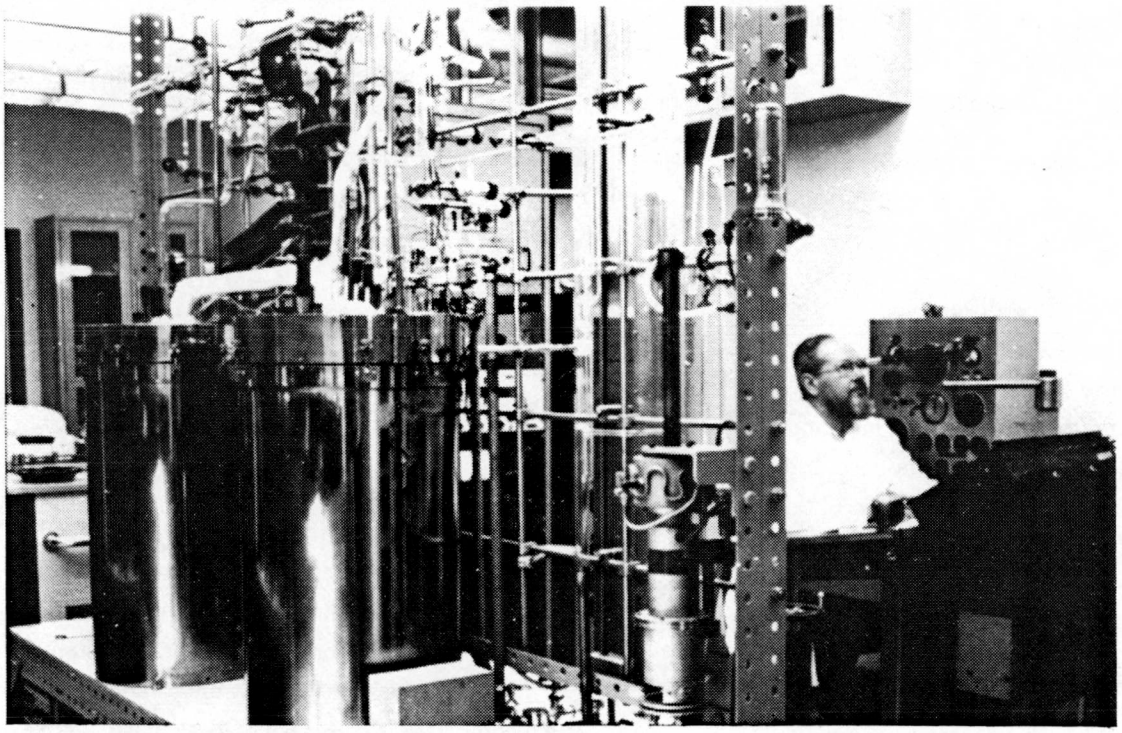
Tripods set up over wells for conducting crosswell seismic studies to image a major fault in the McKittrick field, California – Los Alamos National Laboratory and Chevron Oil Field Research Company



McKittrick crosswell survey: Seismic waves transmitted between wells through low-velocity layers in the oil-producing interval



Preparing the Kratos MS-50 high-resolution mass spectrometer to analyze a deposit from a jet fuel – National Institute for Petroleum and Energy Research



Vapor flow calorimeter: Making measurements of enthalpy of vaporization and vapor Cp – National Institute for Petroleum and Energy Research

Shale oil and heavy petroleum differ from light petroleum in that they both contain considerably more types and greater quantities of nitrogen compounds. If these compounds are not removed in upstream processing they cause serious catalyst poisoning and fuel-quality problems. Accurate, basic thermophysical and thermochemical properties for many of the nitrogen compounds in alternative feedstocks are not available in the literature. Without these basic data (e.g., enthalpy, entropy, vapor pressure) reaction kinetics, process heat requirements, optimum process operating conditions, etc. cannot be calculated. Since it is impractical to synthesize, purify, and measure the thermodynamic properties for all of the nitrogen-containing compounds possible in alternative feedstocks, this project is designed to select for measurement the "key" compounds that have unique molecular groups. When accurate data are available for most key molecular groups, thermodynamic data may be calculated for a given compound by adding the data for all of its component parts. To date 30 unique compounds have been prepared and tested, and the data published. Additional key compounds will be measured as time and funds permit.

Publications: Seven DOE reports and five papers.

3.2.2.3 Environmental-Fate Data Base

Contractor: Lawrence Berkeley Laboratory (LBL), University of California

This project is developing a large information system covering the chemical substances that occur in the waste materials from processing petroleum and alternative feedstocks. The data obtained are arranged in a relational data base. Individual reference source information may be obtained from the bibliographic section of the data base and this information may be cross-referenced to Chemical Properties, Structure, and Synonyms section for details. Ultimately a Process Stream Chemical Characterization section may produce process plant stream information. This data base is approximately 50% complete, but is already being used by oil companies and consultants for quick reference. It is available from LBL free of charge.

3.2.3 University Geoscience Research

DOE signed contracts on eight of ten geoscience proposals selected for award from an AEPT geoscience PRDA in September 1989. The remaining contracts were scheduled to be signed early in FY90. Five university contracts involve resource/reservoir description, and two are in the extraction process area. The remaining three contracts involve research laboratories outside the university system.

3.3 TERTIARY OIL RECOVERY INFORMATION SYSTEM (TORIS)

The Tertiary Oil Recovery Information System (TORIS) is the most comprehensive analytical system of EOR experience in the United States. It includes three data bases and several models for predicting oil recovery:

- EOR project data base, a historical file of EOR projects
- Reservoir/geological information of major U.S. oil fields
- Comprehensive data base of crude oil properties
- BOAST II, a 3-dimensional 3-phase (black oil) simulator
- EOR predictive models, including economic analysis
- Horizontal/slanted lateral well model

The National Petroleum Council (NPC) evaluated and updated the reservoir data base in its 1982-84 study. BPO has since added more production data needed to analyze decline curves, oil reserves, stripper well status, etc. Working with the Interstate Oil Compact Commission (IOCC) and state agencies, BPO completed the reservoir data base for New Mexico and Oklahoma and worked on the Texas

data. Preparation of reservoir data from other states has also started. New geologic data are being added to analyze reservoir heterogeneities and unswept mobile oil. When complete, TORIS will be the only reservoir data base capable of examining the entire U.S. oil resource.

The reservoir models are distributed to industry free of charge. BOAST II, in mainframe and PC versions,is used to simulate reservoir performance under primary or secondary (waterflooding or gas injection) recovery. The EOR predictive models are simple, mechanistic, one-dimensional models, designed for a PC or a mainframe computer. These models generate a projected oil rate vs. time curve for the reservoir (actually for a single well pattern). This predicted production profile is then entered into the economic analysis program to compute discounted cash flow and various profitability indicators. Predictive models are available for steamflooding, in-situ combustion, polymer, surfactant and CO_2 miscible floods. These are continually upgraded and models for other EOR processes are being developed. An infill drilling model is also under development.

Recent enhancement/modifications to TORIS include:

- Impact of state/federal tax changes
- Estimation of unrecovered mobile oil and prediction of its recovery with existing techniques and advanced processes
- Enhancements of the miscible CO2 and surfactant flooding models
- Development of a miscible nitrogen flooding model
- Development of the horizontal/slanted well model
- Modifications of the TORIS timing model

Appendix A shows the main studies performed with the TORIS system over 12 months (July 1988 - July 1989).

Table 2 BPO Technology Transfer Distribution Activities

REPORTS	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	FY 1989
Total No. of Reports Distributed*	60,478	46,703	45,308	33,464	30,993	36,827
Total Individual Requests	10,264	9,379	5,511	7,198	4,418	13,558
No. Orders Received	4,864	3,015	1,556	1,661	1,227	2,427
Av. No. of Requests Per Order	2.11	3.11	3.54	4.33	3.60	5.77
Total No. Reports Published	50	49	53	67	56	87

*Include reports distributed by OSTI

SOFTWARE

BOAST II	Tape	39	31
	PC	-	375
Predictive Model	Tape	15	8
	PC	67	226
Horizontal Well	Tape	-	78
Oil Analysis Data Bank	Tape	3	7

4.0 TECHNOLOGY TRANSFER

The Bartlesville Project Office (BPO) is recognized worldwide as a major resource of petroleum information which includes historical and statistical information, economic and technical analyses, software, and technical reports.

The Technology Transfer Program at BPO requires the cooperative efforts of many people who perform multiple tasks to make the technology transfer process effective. Though the direction and the program itself change frequently, the tasks themselves remain essentially constant.

Long-term research activities dominated the petroleum program through FY88, and thus technology transfer was largely confined to research laboratories of major oil companies and universities. With the increasing emphasis on near and midterm research starting in FY89, BPO has been concentrating its technology transfer effort on the independent oil companies.

4.1 PUBLICATIONS PROGRAM

Members of the petroleum industry have continually acknowledged the importance of this technology transfer activity by requesting information from Bartlesville on petroleum research projects conducted under the auspices of the Federal Petroleum Research Program. In FY 1989, the number of resources available to the industry increased as a result of the many R&D activities managed by BPO. There was also a greater demand for reports, software, and technical assistance. A summary of "Report Distribution Activities FY 1984-FY 1989" is given in Table 2.

Identifying the users is as useful to the technology transfer process as is the information itself. Thirteen user categories of scientific and technical information (STI) have been identified, but only the three largest users are reported each quarter. In FY89, these were: (1) consultants (1,596), (2) U.S. academia (1,423), and (3) research institutes (659). The highest demand for STI was for the following three research areas: (1) chemical recovery (1,532), (2) resource assessment (1,172), and (3) geoscience (760).

BPO published 87 technical reports during FY89 (listed in Appendix B), an increase of 32 from the previous year. The total number of reports distributed in FY89 was 36,827, also an increase from the previous year. Total individual requests increased significantly in FY89 – 13,558 compared to 4,418 in FY88. These figures are expected to continue rising in the coming year, since the number of research projects is increasing.

As the DOE depository of STI, the Office of Scientific and Technical Information (OSTI) in Oak Ridge, Tennessee works closely with the individual DOE offices to coordinate program distribution of all DOE publications. In FY89, OSTI distributed 3,966 copies of reports published by BPO to DOE personnel, contractors, and others identified by BPO

as appropriate recipients of the information.

For the past 15 years, BPO has helped the petroleum community to keep abreast of current research efforts by publishing the quarterly status report on EOR, *Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery*. In FY89 alone, BPO distributed 8,535 copies of this technical report to EOR scientists and researchers.

BPO announces the availability of new reports each quarter in the BPO Publications List. Abstracts summarize research results of petroleum R&D projects in chemical flooding, gas flooding, thermal processes, fundamental petroleum chemistry, MEOR, environmental, geoscience, resource assessment, thermodynamics, and processing and utilization. During FY89, BPO distributed 9,768 copies of this publication.

4.2 DOE NEWS

The press release is an effective technology transfer mechanism for announcing a major research achievement. BPO, in cooperation with the FE Office of Communications, released five "DOE News" items in FY89.

- "New Device that *Sees* Through Old Well Casings Could Help Find Missed Oil and Gas Supplies"
- "Energy Department Picks 10 Organizations to Boost Oil and Gas Geoscience Research Efforts"
- "DOE Makes Available to Industry Computer Program that Predicts Oil Production from Horizontal/Slanted Wells"
- "DOE Develops Personal Computer Version of Oil FieldSimulation Program: Could Assist Smaller Independents"
- "DOE Awards Funds to LSU to Study *Huff 'N Puff* Method of Using Carbon Dioxide to Recover Light Oil"

4.3 CONFERENCES

BPO organized or co-sponsored several conferences, seminars or short courses and participated in other technical meetings with representatives of industry, universities, national laboratories and federal and state agencies. Examples are:

- Oct 88 - DOE-sponsored researchers presented five papers at the 7th International Symposium on Surfactants in Solutions in Ottawa.
- Dec 88 - After attending the annual IOCC meeting in Overland Park, Kansas, BPO representatives participated in a meeting on state oil and gas information and data base management. Representatives attended from geological surveys or regulatory petroleum offices from seven states, and other federal agencies.
- May 89 - NIPER conducted a one-day course on MEOR for 24 operators, researchers, consultants and suppliers.
- Jun 89 - BPO/NIPER organized the Second International Reservoir Characterization Conference in Dallas on June 25-28. The conference attracted some 250 operators and industry personnel.
- Sept 89 - Researchers presented ten papers on EOR research sponsored by BPO, at the American Chemical Society meeting in Miami. Feb 89 - A BPO representative attended the 10th SPE Symposium on Reservoir Simulation in Houston. A presentation on permeability modeling in sandstones was given by a BPO-supported researcher.
- May 89 - BPO participated in the Mississippi Energy Futures Symposium, sponsored by the Mississippi Departments of Energy and Transportation in Jackson.
- Jun 89 - BPO participated in mid-year IOCC meeting in Reno, Nevada.

BPO is working with the Society of Petroleum Engineers (SPE) to organize the Seventh DOE/SPE EOR Symposium, to be held in Tulsa in April 1990. BPO is also co-sponsoring (with the University of Oklahoma) the International MEOR symposium, which will be held in Norman, Oklahoma in May 1990.

4.4 CONTACTS WITH INDEPENDENT OIL OPERATORS

In keeping with the Enhanced Domestic Oil Production Initiative, BPO conducted technology transfer activities tailored mainly for the benefit of small independent oil companies:

- Jan 89 - BPO and HQ officials attended the EOR Technology Transfer Workshop in Mount Vernon, IL. Over 40 independent oil producers participated in the workshop conducted by IOCC and Illinois Oil and Gas Association.
- Mar 89 - BPO presented "Current DOE Research Relevant to the Independent Operators" to about 600 operators attending the Ohio Oil & Gas Association in Columbus. The emphasis of the talk was on infill drilling.
- May 89 - BPO participated in the May 11 IOCC seminar in Lafayette, LA on ways to improve oil and gas production. More than 60 operators, suppliers and consultants attended.
- May 89 - BPO provided training to more than 50 Texas operators in the use of the EOR predictive models, at a seminar in Houston organized by BPO and SPE.
- Jul 89 - A polymer gel treatment, to improve the production profile of a well, has been applied by Cuatro O&G Corp in Texas. Featured at the September 1988 DOE/Hardin Simmons EOR conference, this well treatment is reportedly much less costly than commercial services. It was the subject of discussions at BPO with representatives from Cuatro and Fairleigh Dickinson Research Center.
- Jul 89 - BPO reached agreement with Rougeot Oil & Gas Co. to cost-share the drilling of a horizontal well in Osage County, Oklahoma, to demonstrate the feasibility of extended-reach horizontal wells for enhanced production. Details are given in Section 3.1.5.2.

5.0 SIGNIFICANT EVENTS

Significant events other than those discussed in Section 4.0 may be grouped under the following headings:

- National laboratory/industry partnership
- Federal/state joint efforts
- International cooperation
- Other highlights

5.1 NATIONAL LABORATORY/INDUSTRY PARTNERSHIP

In FY89 DOE launched the Oil Recovery Technology Partnership between two national laboratories (Los Alamos and Sandia) and the petroleum industry. The objective of this partnership is to stimulate, facilitate and coordinate technology development and transfer. The concept is focused to use and foster technologies largely derived from DOE-funded weapons and energy research. BPO provides guidance to the Partnership as an integral part of DOE's National Petroleum Research Program. The Partnership has a steering committee with members from all three partners, and an industry review panel. Both include a cross section of the petroleum industry, including leaders from major oil companies, independents and service companies.

The first collaborative project of the Partnership is cross-well seismic surveying, a critical emerging technology which should benefit from the national laboratory/petroleum industry interaction. In this technique a seismic signal is generated in a well, and the response is monitored with a receiver placed in a second well. The technique produces a detailed tomographic image of the reservoir.

Planning meetings were held in Bartlesville in November, and in Dallas in December 1988. The Partnership conducted a forum on cross-well seismic on April 25, 1989 in Dallas. Five projects were discussed and two of them were selected to commence in FY89. These are discussed in Section 3.2.1.3.

Two other projects pertain to improving oil recovery from two reservoirs in New Mexico. In one, microseismic mapping is being used in improving waterflood design for a fractured dolomite reservoir. In the other, the Partnership is developing improved methods for determining reservoir properties and their effect on recovery from a very tight sandstone reservoir.

5.2 INTERNATIONAL COOPERATION

DOE has cooperative agreements for joint R&D with corresponding government agencies in Great Britain, Italy, Mexico, Norway and Venezuela. DOE also supports the activities of the United Nations Institute of Training and Research (UNITAR) in disseminating R&D of heavy oil and tar sands. In

FY89 DOE funded, along with other countries, the Information Center for Heavy Oil and Tar Sands at the UN in New York.

The following were the main international activities of BPO:

- Oct 88 - EOR annexes to the Cooperative Agreement with the Norwegian Institute for Energy Technology were prepared and submitted to HQ for approval.
- Oct 88 - BPO delivered Reports 5 and 6, on characterization of the Cerro Negro heavy oil, to INTEVEP, Venezuela.
- Jun 89 - BPO/Norwegian Institute scientists reviewed progress on the proposed Annex II to their agreement.
- Aug 89 - The U.S./Venezuela (DOE/MEMV) Joint Steering Committee met on August 24 for a status report on the nine active annexes, and signed several annex extensions. The final report on characterization of the Cerro Negro heavy oil was completed, bringing to a close the 9-year analytical chemistry research. (Refer to Section 3.2.2)

5.3 FEDERAL/STATE JOINT EFFORTS

- Nov 88 - Two cost-shared contracts for EOR field tests were signed: (1) Louisiana State University will conduct a 2-year project of cyclic CO2 injection; (2) University of Oklahoma/Mesa Petroleum (formerly Tenneco) will undertake a 3-year MEOR project to evaluate the ability of microorganisms to plug the permeable zone, thereby diverting water to unswept portions of the reservoir.
- Jan 89 - FE and BPO officials participated in a meeting at New Mexico Technical University in Socorro, with state officials and representatives from industry, universities and national laboratories. The aim was to improve research cooperation and technology transfer, and to provide small independents with means to prolong the producing life of stripper wells.
- Geoscience Institute directors reviewed geoscience research needs. BPO Deputy Director and TORIS Program Coordinator, presented the TORIS system at the meeting.
- Mar 89 - BPO participated in the first meeting of the Hydrocarbon Geoscience Research Strategy task force at the Office of Geoscience Research (OGR).
- The BPO Director attended a post-project review of the nearly $3 million research grant over the period Nov 86-Jan 89 at the University of Oklahoma Energy Center. The grant funded 22 projects in fossil-energy research and generated follow-up research funded by industry and government.
- Apr-Jun 89 - DOE awarded research projects to universities in Texas, and the Geological Surveys of Alabama and Illinois, under Memoranda of Understanding (MOU's) administered by BPO.

5.4 OTHER HIGHLIGHTS

- Mar 89 - BPO provided results from a TORIS study on the impact of tax incentives on oil production to Senator Domenici of New Mexico.
- May 89 - DOE extended the cooperative agreement with IITRI to operate NIPER for 18 months through March 1991.
- Jun 89 - DOE-sponsored research at the University of Texas was rated very favorably by industry sponsors (seven U.S. and six foreign companies).
- Jul 89 - ParaMagnetic Logging Corp. announced a breakthrough in DOE-sponsored research in measuring formation resistivity in cased wells.
- BPO project managers presented a status briefing of EOR research activities to FE officials in Bartlesville on July 17-18.

6.0 STRATEGY FOR THE NINETIES

The strategy of the National Petroleum Research Program in the seventies and eighties was to conduct long-term, high-risk research that industry did not engage in actively. However, in the late eighties it became obvious that DOE/FE would have to shift its emphasis to near- and mid-term research, if only to preserve access to the remaining petroleum by applying advanced recovery methods.

The Fossil Energy strategy for the nineties, is contained in the Hydrocarbon Geoscience Research Strategy (June 1989) and summarized in Section 2.0. The near-, mid-, and long-term goals and objectives of the National Petroleum Research Program are discussed in the following sections.

6.1 NEAR-TERM STRATEGY

The goal of near-term research is to maintain access to the resource in danger of abandonment and to increase domestic production.

The main objectives are to:

- Utilize existing methods to characterize reservoir heterogeneities, architectures, and flow paths of high-priority classes of reservoirs by:
  - formalizing description methods
  - defining reservoir geological classes
  - updating TORIS reservoir data base
- Design and test the following applicable, available production technologies:
  - targeted infill drilling
  - horizontal drilling
  - profile modification
  - polymer flooding
- Develop environmentally acceptable, reversible plugging techniques.
- Study the environmental impact of advanced extraction processing and establish criteria for effective management of oilfield production wastes.
- Define technology transfer targets and their needs.
- Update TORIS to incorporate research results.

6.2 MID-TERM STRATEGY

The mid-term research goal is to maximize recovery from high-potential reservoirs.

The principal objectives are to:

- Develop improved methods to geologically characterize high-potential reservoirs that are economic by developing:
  - improved instrumentation technologies and interpretation techniques
  - improved scaling techniques
  - quantitative geological models

  - methods for predicting location and condition of the remaining oil
- Design and test advanced production technologies
  - develop improved simulators incorporating geological models
  - gas, chemical, and microbial recovery technologies
- Define technology transfer targets and their needs
- Update TORIS to include results of research

6.3 LONG-TERM STRATEGY

The long-term research goal is to improve our understanding of the oil resource and the technologies for extracting the resource.

The main objectives are to:

- Improve fundamental understanding of reservoir types
  - evaluate novel characterization technology
  - develop basin analysis techniques to identify subtle traps
  - perform rock-fluid research
  - develop geostatistical techniques to predict heterogeneities
- Improve technical recovery efficiency
  - evaluate novel extraction & engineering techniques
  - develop improved simulation techniques
  - improve process recovery technologies
- Define technology transfer targets and their needs
  - update TORIS to include research results
  - continue to improve understanding of the oil resource and extraction technologies through use of TORIS and other technology transfer mechanisms.

APPENDIX A

LIST OF MAJOR TORIS PROJECTS
(July 1988 - July 1989)

Project	Start Date	End Date	Performed For	Number Of Oil Prices	Range Of Oil Prices	Technology Level Analyzed	Scope Of Analysis
Evaluation of unrecovered mobile oil in Texas, Oklahoma, New Mexico	8/1/88	10/15/89	DOE	7	$12-$36	IMP/ADV	• Infill drilling and advanced secondary processes
	12/15/88	1/15/88	DOE	7	$12-$36	IMP/ADV	• Additional sensitivity analysis
Analysis of federal royalty incentives to encourage EOR in New Mexico	9/26/88	9/30/88	DOE	5	$16-$32	IMP	• CO2 flooding only • Base tax structure • Two federal royalty incentive options
Potential for CO2 flooding in Wilmington Field area, California	10/12/88	12/22/88	Williams Inc.	6	$20-$60	IMP	• Miscible CO2 flood • Qualitative analysis of immiscible flooding • Up to five CO2 prices
Development of statistical correlations to estimate investments and operating costs for enhanced oil recovery projects	10/24/88	12/15/88	DOE (Folstein)	4	$20-$50	IMP/ADV	• Correlations designed for system dynamic model using EIA price track
Preliminary analysis of EOR and UMO potential in Texas	11/1/88	12/5/89	IOCC	7	$12-$36	IMP/ADV	• NPC fields only • EOR and UMO processes • Base tax structure • State severance tax incentives

IMP: Implemented technology
ADV: Advanced technology

LIST OF MAJOR TORIS PROJECTS
(July 1988 - July 1989)

Project	Start Date	End Date	Performed For	Number Of Oil Prices	Range Of Oil Prices	Technology Level Analyzed	Scope Of Analysis
Final analysis of EOR and UMO potential in Texas	1/26/89	5/20/89	IOCC	7	$12-$36	IMP/ADV	• Combined BEG and NPC fields • EOR and UMO processes • Base tax structure • State severance tax incentives
Analysis of federal tax incentives to encourage EOR in the U.S.	3/3/89	3/6/89	Sec'y of Energy	3	$16-$22	IMP	• Base tax structure • Three federal tax incentive options
	3/22/89	3/28/89	Sec'y of Energy	3	$16-$22	IMP	• Two additional incentive options
Analysis of federal tax incentives to encourage EOR in the U.S.	3/7/89	3/10/89	Senator Dominici	4	$20-$32	IMP	• Base tax structure • Two federal tax incentive options
	3/14/89	3/22/89	Senator Dominici	4	$20-$32	IMP	• Three additional tax incentive options
Preliminary assessment of EPA oil and gas waste management regulations	4/26/89	ongoing	DOE	4	$14-$32	IMP	• EOR and UMO resources in TX, OK, and NM • Up to ten regulatory scenarios
Geological distribution of UMO and EOR reserves in TX, OK, and NM	5/3/89	5/22/89	DOE	2	$20-$32	IMP/ADV	• To identify geologic plays with significant UMO and EOR potential for R&D purposes

LIST OF MAJOR TORIS PROJECTS
(July 1988 - July 1989)

Project	Start Date	End Date	Performed For	Number Of Oil Prices	Range Of Oil Prices	Technology Level Analyzed	Scope Of Analysis
National EOR potential at higher prices	5/23/89	6/2/89	DOE	4	$30-$60	IMP/ADV	• To estimate maximum potential for EOR reserves in the Lower-48 states
Impact of redrilling existing wells (due to abandonment) on EOR reserves in New Mexico	5/26/89	6/8/89	DOE	7	$20-$75	IMP	• CO2 flooding in New Mexico • Four redrilling options: 20%, 40%, 60%, and 100% of existing wells
Analysis of federal policy options to increase oil recovery from domestic reservoirs	5/31/89	ongoing	DOE (Pyrdol)	7	$12-$36	IMP/ADV	• EOR and UMO processes • Fields in TX, OK, and NM • Base tax structure • Up to three federal tax incentive options • State tax incentives • Combined state/federal tax incentives

APPENDIX B

TECHNICAL REPORTS ISSUED IN FY89 *

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
GENERAL RESEARCH				
NIPER-320	1987 Annual Report.	NIPER	Oct 88	DE88001234
NIPER-357	FY89 Annual Research Plan.	NIPER	Nov 88	DE89000701
DOE/BC-89/3/SP	Handbook for Personal Computer Version of BOAST II: A Three-Dimensional, Three-Phase Black Oil Applied Simulation Tool.	BPO	Jan 89	DE89000725
DOE/BC/14286-1	Proceedings of Improved Oil Recovery Conference, Abilene, Texas., Sep 11-13, 1988.	Fairleigh Dickinson Research Center	Mar 89	DE89000732
NIPER-400	1988 Annual Report.	NIPER	Sep 89	DE89000759
CHEMICAL FLOODING				
DOE/ET/13077-130	Commercial Scale Demonstration Enhanced Oil Recovery By Micellar-Polymer Flood Final Report.	Marathon Oil Co.	Nov 88	DE88001252
DOE/BC/10830-8	A Review of the Loudon Surfactant Flood Pilot Test	K&A Technology	Nov 88	DE89000706
DOE/BC/10830-9	An Evaluation of the Big Muddy Field Low-Tension Flood Demonstration Project.	K&A Technology	Dec 88	DE89000713
DOE/BC/10830-10	An Evaluation of the Robinson M-1 Commercial Scale Demonstration of Enhanced Oil Recovery by Micellar-Polymer Flood.	K&A Technology	Dec 88	DE89000714
DOE/BC/10841-10	Modeling and Optimizing Surfactant Structure Improved Oil Recovery by Chemical Flooding at the University of Texas. Annual Report for the Period Oct 1986-Sep 1987.	Univ of Texas	Dec 88	DE89000712
DOE/BC/10843-10	Investigation of the Application of Gelled Polymer Systems for Permeability Modification in Petroleum Reservoirs. Second Annual Report for the Period Oct 1986-Sep 1987.	Univ of Kansas	Nov 88	DE88001250
DOE/BC/10846-10	Modelling and Scale-up of Chemical Flooding. Second Annual Report for the Period Oct 1986-Sep 1987.	Univ of Texas at Austin	Nov 88	DE88001251
DOE/BC/10847-10	Enhanced Oil Recovery Through In-Situ Generated Surfactants Augmented by Chemical Injection. Annual Report for 1986-1987.	Illinois Institute of Technology	Nov 88	DE88001249
NIPER-339	Crosslinking Dry Xanthan Gum for Profile Modification in Oil Reservoirs. Final Report.	NIPER	Oct 88	DE88001239
NIPER-340	Mineral-Alkali Reactions Under Dynamic Conditions.	NIPER	Nov 88	DE88001253

* Excluding quarterly progress reviews and reprints

TECHNICAL REPORTS ISSUED IN FY89 *

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
NIPER-368	Effects of 1-Butanol on the Micellization of Dodecyltrimethylammonium Bromide at Elevated Temperatures.	NIPER	Jan 89	DE89000723
NIPER-375	Low-pH Alkaline Chemical Formulations.	NIPER	Jan 89	DE89000724
DOE/BC/10848-15	Adsorption from Flooding Solutions in Porous Media. A Study of Interactions of Surfactants and Polymers with Reservoir Minerals. Annual Report for the Period Oct 1, 1987 - Sep 30, 1988.	Columbia University	Mar 89	DE89000733
DOE/BC/10844-15	Polymers for Mobility Control in Enhanced Oil Recovery. Third Annual Report for the Period Oct 87- Sep 88.	Univ of Southern Mississippi	Apr 89	DE89000738
NIPER-385	Surfactant Loss: Effects of Temperature, Salinity, and Wettability.	NIPER	May 89	DE89000745
THERMAL RECOVERY				
DOE/BC/14126-1	An Analytical Study of Transient Behavior of Nonhomogeneous Linear and Radial Systems -- SUPRI TR 60.	SUPRI	Nov 88	DE88001245
DOE/BC/14126-2	Detecting Linear Barriers by Type Curve Analysis -- SURPI TR 61	SURPI	Nov 88	DE88001246
DOE/BC/14126-3	Foam and Emulsion Effects on Gas Driven Oil Recovery -- SURPI TR 62.	SUPRI	Nov 88	DE88001247
DOE/BC/14126-4	The Effects of Metallic Additives on the Kinetics of Oil Oxidation Reactions in In-Situ Combustion -- SURPI TR 63.	SUPRI	Nov 88	DE88001248
DOE/BC/14126-5	SUPRI Heavy Oil Research Program. Eleventh Annual Report for the Period Oct 1, 1986-Sep 30, 1987. SURPI TR 64.	SUPRI	Nov 88	DE89000703
NIPER-338	Steamflooding Light Crude Oil Reservoirs -- A state-of-the-Art Review.	NIPER	Nov 88	DE88001238
DOE/BC-89/1/SP	Supporting Technology for Enhanced Oil Recovery -- EOR Thermal Processes.	Republic of Venezuela Ministry of Energy & Mines and U.S. DOE	Dec 88	DE89000702
DOE/SF/11999-2	Chemical Additives for Improving Steamflood Performance. Final Report for Jan 1, 1989 -- May 31, 1987.	Univ of California	Jan 89	DE89000722
DOE/BC/14126-6	On the Use of Pressure and Tracer Test Data for Reservoir Description -- SUPRI TR 65.	SUPRI	Apr 89	DE89000736
DOE/BC/14126-7	An Introduction of Computerized X-Ray Tomography for Petroleum Research -- SUPRI TR 66.	SUPRI	Jun 89	DE89000752
DOE/BC/14126-8	SUPRI Heavy Oil Research Program. Twelfth Annual Report for the Period	SUPRI	Jun 89	DE89000753

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
	Oct 1, 1987-Sep 30, 1988 -- SUPRI TR 67.			
DOE/BC/14126-9	Nucleation and Pore Geometry Effects in Capillary Desorption Processes in	Univ. of Southern California	Aug 89	DE89000757
DOE/BC/14126-10	Capillary Effects in Steady-State Flow in Heterogeneous Cores.	Univ. of Southern California	Aug 89	DE89000758
CARBON DIOXIDE FLOODING				
DOE/BC/10830-7	A Review of the West Sussex Unit CO2 Flood Project.	K&A Technology	Nov 88	DE89000705
NIPER-362	The Use of Entrainers for Improving Gas Mobility Control and Displacement Efficiency.	NIPER	Nov 88	DE89000704
DOE/BC/10830-11	An Evaluation of the Weeks Island "S" Sand Reservoir B Gravity Stable CO2 Displacement Project, Iberia Parish, Louisiana.	K&A Energy Consultants, Inc.	Feb 89	DE89000727
DOE/MC/21136-17	Improvement of CO2 Flood Performance. Third Annual Report for Oct 1, 1986 -- Sep 30, 1987.	New Mexico Institute of Mining & Technology	Jan 89	DE89000720
DOE/BC/10830-12	An Evaluation of the CO2 Pilot Maijamar Field. Lea Country, NM.	K&A Energy Consultants, Inc.	Feb 89	DE89000728
DOE/MC/12004-6	Weeks Island Gravity Stable CO2 Pilot. Final Report.	Shell Offshore Inc.	Jan 89	DE89000719
DOE/MC/21136-21	Improvement of CO2 Flood Performance. Fourth Annual Report for the Period Oct 1, 1987- Sep 30, 1988.	New Mexico Institute of Mining & Technology	Jul 89	DE89000765
GAS FLOODING				
NIPER-308	Laboratory Study of Nitrogen Miscible Displacement of Light Oil.	NIPER	Sep 89	DE89000762
GEOSCIENCE				
NIPER-235	Effect of Reservoir Heterogeneities on Waterflood and EOR Chemical Flood Performance.	NIPER	Oct 88	DE88001237
NIPER-286	Verification of Geological/Engineering Model in Waterflood Areas.	NIPER	Dec 88	DE89000710
NIPER-372	New Techniques of Pore-Scale Visualization of Fluids in Porous Media: The Effect of Pore Structure on Fluid Distribution.	NIPER	Mar 89	DE89000731
NIPER-378	Determining Petrophysical Properties of Reservoir Rocks by Image Analysis.	NIPER	Mar 89	DE89000734
DOE/BC/10849-10	Systematic Procedure for Reservoir	Univ of Texas	Nov 88	DE89000707

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
	Characterization. Annual Report for the Period Oct 1, 1986-Sep 30, 1987.	at Austin		
NIPER-390	Integrated Reservior Assessment and Characterization. Final Report for the Period Oct 1, 1985-Sep 30, 1988.	NIPER	May 89	DE89000743
NIPER-392	The Effects of Viscous Forces on Three-Phase Relative Permeability. Topical Report.	NIPER	Apr 89	DE89000737
MICROBIAL EOR				
NIPER-356	Microbial-Enhanced Waterflood Field Experiment.	NIPER	Jan 89	DE89000718
DOE/BC/14084-6	Microbial Field Pilot Study. Final Report for the Period Dec 15, 1986-Mar 31, 1988.	Univ of Oklahoma	Jan 89	DE89000721
DOE/BC/14014-9	Microbiological Techniques for Paraffin Reduction in Producing Oil Wells. Final Report	Alpha Environmental Corporation	Apr 89	DE89000741
NIPER-272	MEOR Data Base and Evaluation of Reservoir Characteristics for MEOR Projects.	NIPER	Sep 89	DE89000764
NOVEL TECHNIQUES				
NIPER-326	Simulation of Production from Wells with Horizontal/Slanted Laterals. Final Report.	NIPER	Mar 89	DE89000711
NIPER-369	Development of Novel EOR Methods. Foams for Mobility Control in Surfactant Flooding.	NIPER	Jan 89	DE89000715
PETROLEUM PROCESSING				
NIPER-352	Stability, Compatibility, and Related Problems of Additives in Naval Distillate Fuels Derived from Lower Quality Feedstocks.	NIPER	Jan 89	DE89000717
DOE/BC/99882-25	Viscosity and Spray Effects of Coal slurry Diesel Fuels. Final Report.	NIPER	Feb 89	DE89000726
THERMODYNAMICS				
NIPER-333	Thermodynamics of Materials in the Range C10-C16: Data Base Description, Uses, and Future Work Recommendations.	NIPER	Oct 88	DE88001243
NIPER-334	Thermodynamics of Materials in the Range C10-C16: Data Base Reference Manual.	NIPER	Oct 88	DE88001244
NIPER-337	The Thermodynamic Properties of the Five Benzoquinolines.	NIPER	Oct 88	DE88001240

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
NIPER-360	High-Temperature Heat-Capacity Measurements and Critical Property Determinations Using a Differential Scanning Calorimeter (Development of Methdology and Application to Pure Organic Compounds). Topical Report.	NIPER	Oct 88	DE88001241
NIPER-379	Preliminary Thermodynamic Studies on the Hydrodenitrogenation of Indole.	NIPER	Dec 88	DE89000708
NIPER-380	The Thermodynamic Properties of Polycyclic Aromatic Oxygen-Containing Compounds I. Chroman and Isochroman.	NIPER	Dec 88	DE89000709
NIPER-345	The Thermodynamic Properties of 4-Methylphenanthrene (Application of the Group-contribution Methology to Alkyl-aromatics).	NIPER	Jan 89	DE89000716
NIPER-364	Comparison of Thermodnyamics of Nitrogen and Sulfur Removal in Heavy Oil Upgrading. Part I. Acyclic and Monocyclic Compounds.	NIPER	Jun 89	DE89000747
NIPER-82	Thermodynamic Properties of Biphenyl.	NIPER	Jun 89	DE89000750
NIPER-399	The Thermodynamic Properties of 1, 2, 3, 4- and 5, 6, 7, 8-Tetrahydroquinolines.	NIPER	Apr 89	DE89000729
NIPER-415	Thermodynamics and the Hydrodenirogenation of Indole.	NIPER	Jun 89	DE89000751
NIPER-395	High-Temperature Heat-Capacity Measurements and Critical Property Determinations Using A Differential Scanning Calorimeter -- Results of Measurements on Toluene, Tetralin, and JP-10.	NIPER	Jun 89	DE89000749
NIPER-319	Determination of Some Pure Compound Ideal-Gas Enthalpies of Formation.	NIPER	Jun 89	DE89000748
NIPER-403	Thermodynamic Equilbria in the Biphenyl/Hydrogen System (The Power and Limitations of Group Additivity Estimations).	NIPER	Jul 89	DE89000754
FUNDAMENTAL PETROLEUM CHEMISTRY				
NIPER-160	Analysis of Heavy Oils: Method Development and Application to Cerro Negro Heavy Petroleum, Distillation and Determination of Routine Chemical/ Physical Properties.	NIPER	Oct 88	DE88001235
NIPER-161	Analysis of Heavy Oils: Method Development and Application to Cerro Negro Heavy Petroleum, Preliminary Separation and Analysis of Acid, Base, Saturate, and Neutral-Aromatic	NIPER		DE88001236

REPORT NUMBER	TITLE	ISSUING ORGANIZATION	DATE	NTIS ORDER NUMBER
	Fractions.			
NIPER-325	Analysis of Heavy Oils: Method Development and Application to Cerro Negro Heavy Petroleum, Detailed Separation and Analysis of Sulfur Compounds.	NIPER	Oct 88	DE88001242
NIPER-323	Analysis of Heavy Oils: Method Development and Application to Cerro Negro Heavy Petroleum. Detailed Separation and Analysis of Basic Compounds.	NIPER	Jun 89	DE89000746
NIPER-396	Retention Indices, Relative Response Factors, and Mass Spectra of Trifluoro-acetate Esters of Phenolic Compounds Determined by Capillary GC/MS.	NIPER	Apr 89	DE89000739
NIPER-200	The Effects of Degree of Aromaticity and Alkyl Substitution of Polyaromatic Hydrocarbons on Instrumental Response Factors.	NIPER	Sep 89	DE89000761